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SUNFLOWER POWER CONVERSION SYSTEM

[14th] QUARTERLY REPORT

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Jay W. Picking, Jr.

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JUNE 1963 — AUGUST 1963

TAPCO Div. a division of

Thompson Ramo Wooldridge, Inc.,

Cleveland, Ohio

8931002

NOTICE

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LIST OF ILLUSTRATIONS

I. PROJECT OBJECTIVES

The Sunflower program objectives are to accomplish fabrication, test, and development tasks oriented toward confirming the conceptual validity and performance feasibility of a solar-powered 3 Kw mercury Rankine power conversion system. Major items include solution to long-term, high temperature lithium hydride containment, demonstration of component operation and endurance integrity, experimental confirmation of the design integrity of the aluminum honeycomb petaline collector, and operational integrity of the integrated Rankine system.

II. PROJECT OBJECTIVES FOR THE REPORTING PERIOD OF JUNE 1, 1963 THROUGH SEPTEMBER 1, 1963

Endurance testing of turbo-alternator CSU I-3A will be continued.

Operation of the workhorse loop will be continued, and shall be directed toward evaluating the hydrogen removal capabilities of a centrifugal separator. In addition, testing of the hydrogen swallowing of the jet centrifugal pump will be continued.

The force circulation mercury corrosion loop testing will be continued on its endurance test objectives.

Work on Solar Collector and Condenser Subcooler Topical Reports will be continued.

III. PROJECT PROGRESS DURING THE REPORTING PERIOD

PROJECT MANAGEMENT

NASA direction of the Sunflower program has resulted in the cancellation of additional system testing and the shifting of funding to the continuation of turbo-alternator CSU I-3A test. The general aim of the research and development work to be conducted includes the long term evaluation of turbo-alternator endurance capability and the completion of material support work. The latter includes hydrogen containment, centrifugal pump hydrogen swallowing capability, and hydrogen removal from operating test rigs.

Several proposals were submitted to NASA for continuation of some basic areas in the Sunflower program which are felt to require additional hardware test efforts. These include resumption of system testing; design, fabrication and testing of a flight weight boiler/heat storage unit; and continuation of the endurance objectives and material support work.

During the reporting period, data reduction and analysis has been continued on a full basis, reducing data for the CSU I-3A endurance run.

TEST RIG DESIGN AND FABRICATION

Turbo-alternator test facility activities during the quarter have been conducted in support of the endurance turbo-alternator test. This particular turbo-alternator test rig has accumulated in excess of 7400 hours total operational time while conducting component checkout and endurance test of Sunflower component hardware. Since the last modification of various portions of the test equipment,reported in the March to May 1963 Quarterly Progress Report, this test rig has accumulated approximately 3700 hours of continuous operation.

Several small problems have been confronted and successfully remedied while maintaining continuous operation of the turbo-alternator unit. These are:

1. A minute leak was detected in the test rig boiler inlet line which has resulted in a small loss of inventory from the component test rig. Due to the location of the apparent leak, no rework has been attempted while continuing operation due to its precarious position and the possibility of causing line rupture and a spillage of approximately 1500 lb of 1000°F mercury. The leakage has been erratic and appears to be self-plugging. The maximum leakage experienced over a 24 hour period has been 1170 grams, the minimum approximately zero.

2. At various intervals throughout the turbo-alternator test program, commercial centrifugal mercury pumps utilized to supply various flows have had failures. These failures have been detected after forced shut down caused

by outside agencies. For instance, a power failure from the commercial power station occurred which resulted in a loss of electric power to the chem-pump for a period of about 30 seconds. In such a situation, the rig is designed so that a second auxiliary pump is automatically switched on the line and takes over the pumping requirements when the operating pump output pressure decreases beyond a set point. Therefore, after the automatic switching had occurred, the first pump was removed from the rig and disassembled. It was noted that a bearing had experienced a notch sensitive crack, which most probably occurred during the rapid shut down and uneven cooling. Similar instances have occurred subsequently which resulted in the tear down and inspection of another pump which also exhibited the same notch sensitive cracking of a bearing sleeve. The pumps have been rebuilt and again placed back in service.

3. A water-to-mercury heat exchanger developed a water leak which allowed water to enter the test rig plumbing. The presence of water in the system resulted in erratic condenser performance, effects on alternator bearing flow and pressure relationships, and general removal of the water through a vacuum pump trap. This resulted in forcing off-design condenser pressures on the turbo-alternator unit while the rig was opened and the water removed. The effects on unit performance within operational capability did not seriously affect the unit performance or test objectives although temporary changes have been noted in several parameters. In order to allow cooling in the heat exchanger which developed the leak, it was replumbed to be a mercury-to-mercury heat exchanger; the subsequent leak which occurred did not affect rig performance. This particular heat exchanger is not as effective as the water-to-mercury exchanger because of the flow rates and temperature gradients which are permissible with the secondary mercury cooling loop.

4. During this test, other minor problem areas have been encountered including such items as the loss of thermocouples, automatic control features of the superheater, and various mercury and air leaks at various non-welded fitting junctions throughout the test rig plumbing.

SOLAR COLLECTOR

All scheduled testing of the solar collector has been completed, and has encompassed deployment and vibration testing with corresponding optical inspection for detection of collector damage. The collector passed all test objectives and exhibits the potential capability of the collector to withstand the boosting and orbital flight environments.

Additional efforts on the project resulted in the data reduction and analysis of the test parameter and the preparation of the Solar Collector Topical Report, which covers all aspects of the solar collector development program. The report has been completed in rough draft form and is currently being prepared for NASA approval.

TURBO-ALTERNATOR

Endurance testing of turbo-alternator CSU I-3A has accumulated a total of 4066 hours of operation at the end of this quarter. The unit has continued to operate excellently and continuously from its second start-up on April 16, 1963. Since that time, the unit has accumulated 3297 hours of continuous operation. The performance of the unit has been nearly perfect in that all parameters have remained within specification and total power output of the unit has remained constant. That the unit and test rig have performed for this period indicates that the major changes which were reported earlier have corrected the problem areas which resulted in deposit formations and resultant power decays in previously tested turbo-alternators.

The resulting conclusions are indicative of the close attention which must be paid to minor details in the test rig. The results of this test are extremely important and enlightening since the test is being conducted solely in a 316 SS test rig which was not originally designed for endurance test capability. Since this test rig generates an order of magnitude more corrosion product from a temperature standpoint and since it presents a larger area exposed to mercury, it indicates that fabrication and testing of flight material systems should be considerably easier to obtain than the objectives which have been accomplished on this test.

Throughout the test, the unit has many times demonstrated its ability to withstand off-design temperature, pressure, and other parametric variations. Test rig difficulties have resulted in requiring the unit to operate at turbine exhaust pressures near atmospheric pressure, creating exhaust temperatures approaching 670°F. Also, a malfunction of a water-to-mercury heater exchanger allowed water to enter the mercury cycle which was transported to the mercury condenser where it was removed from the system by means of a vacuum pump. The water-to-mercury leakage in the heat exchanger was corrected, while the unit remained in operation, by modifying the heat exchanger to operate as a mercury-to-mercury heat exchanger and allowing subsequent leakage to occur which would not affect cycle operating conditions.

Some of the data which have been accumulated on the turbo-alternator endurance test are presented in Figures 1 through 3. The data are typical of turbo-alternator performance and endurance life objectives and attest that the unit has been operating within design specifications for the length of the subject run. The parameters indicate the extreme steady state which has prevailed throughout the endurance test. The changes shown on alternator and turbine bearing pressure while at constant flow are indicative of a slight bearing clearance change with time. The magnitude of the clearance change which would be anticipated for the flow pressure variations is approximately 50 millionth of an inch. It is our belief that there is no actual metal dimensional changes, but that an extremely thin film of mercury impurities is being deposited on the bearing surface causing the small changes which have been noted. It should be emphasized that the design specifications for the bearings allow pressure fluctuations from approximately 250 to 450 psia inlet pressure and flow varying from 3 to 6.5 lb/per min for the journal bearings. All test data lie well within the specifications.

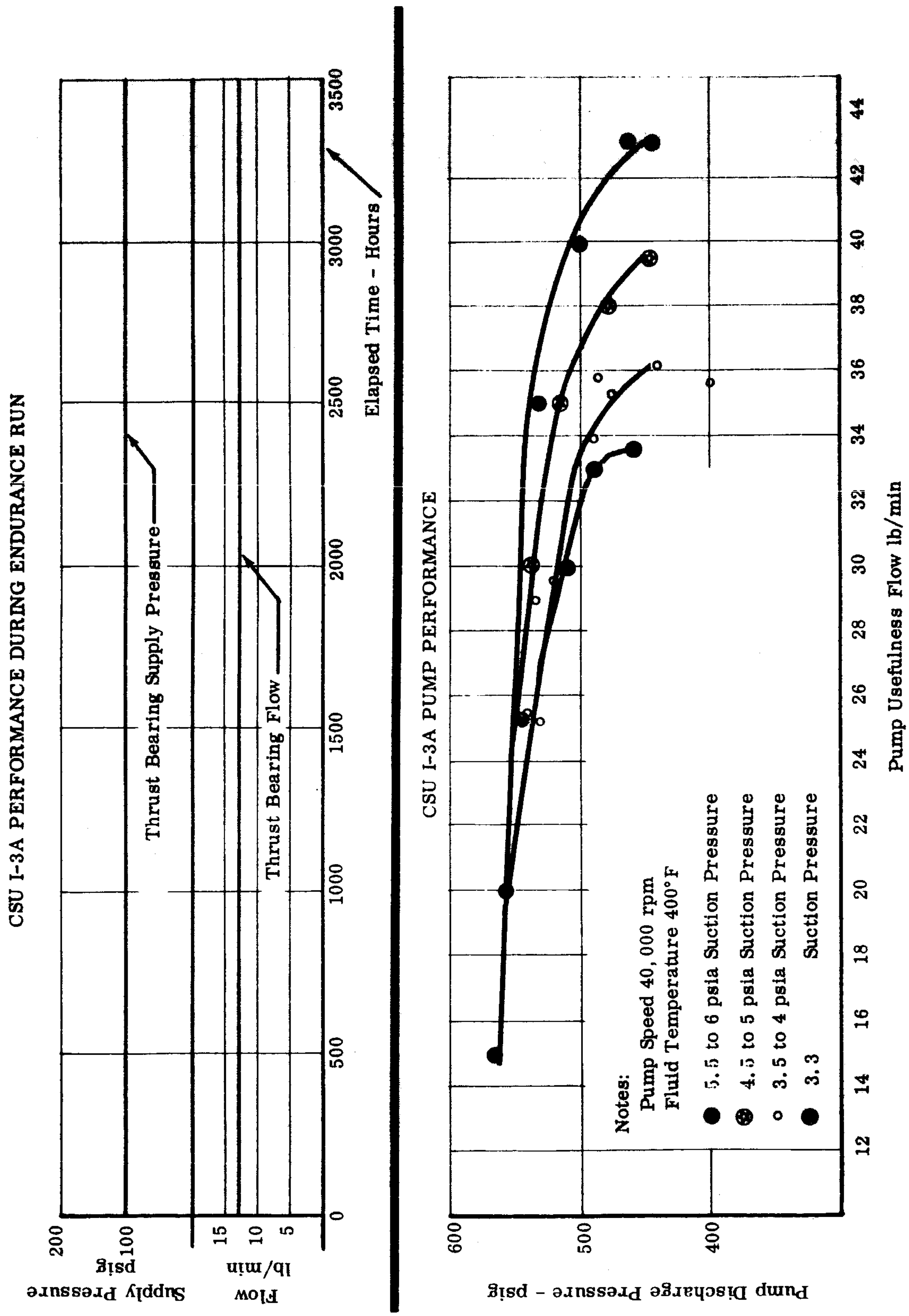

CSU I-3A PERFORMANCE DURING ENDURANCE RUN
Thrust Bearing Supply Pressure
Thrust Bearing Flow
Elapsed Time - Hours
0
500
1000
1500
2000
2500
3000
3500
200
100
Supply Pressure psig
15
10
5
Flow lb/min
CSU I-3A PUMP PERFORMANCE
Notes:
Pump Speed 40,000 rpm
Fluid Temperature 400°F
5.5 to 6 psia Suction Pressure
4.5 to 5 psia Suction Pressure
3.5 to 4 psia Suction Pressure
3.3 Suction Pressure
600
500
400
Pump Discharge Pressure - psig
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
Pump Usefulness Flow lb/min

FIGURE 1

CSU I-3A PERFORMANCE DURING ENDURANCE RUN

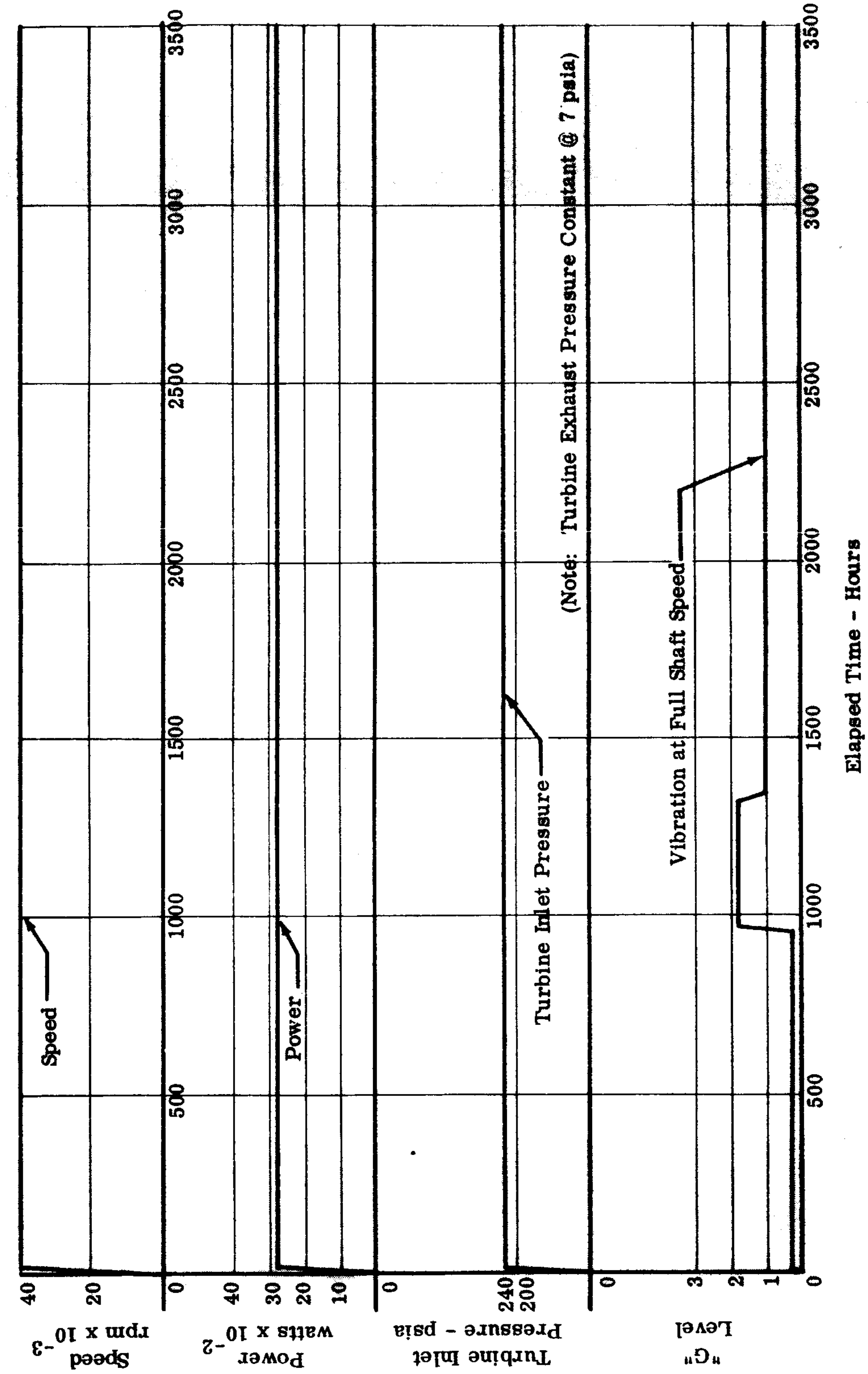


FIGURE 2

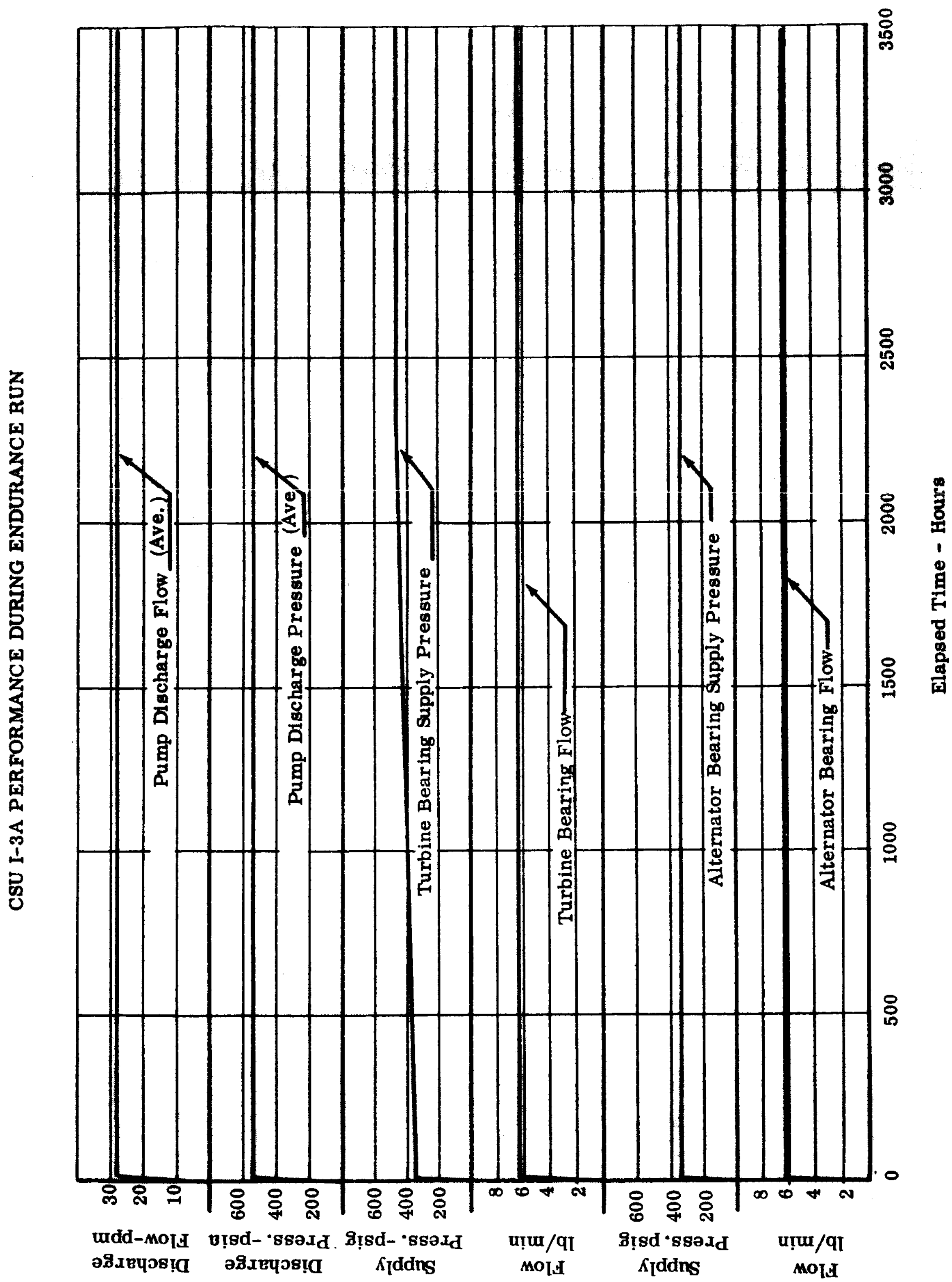

CSU I-3A PERFORMANCE DURING ENDURANCE RUN
Pump Discharge Flow (Ave.)
Pump Discharge Pressure (Ave.)
Turbine Bearing Supply Pressure
Turbine Bearing Flow
Alternator Bearing Supply Pressure
Alternator Bearing Flow
Elapsed Time - Hours
0
500
1000
1500
2000
2500
3000
3500
Discharge Flow-ppm
30
20
10
Discharge Press.-psia
600
400
200
Supply Press.-psig
600
400
200
Flow lb/min
8
6
4
2
Supply Press. psig
600
400
200
Flow lb/min
8
6
4
2

FIGURE 3

Lithium Hydride Containment

Hydrogen permeability measurements have been continued and, during the reporting period, the following samples have been evaluated:

1. Evaluation of the permeability of hydrogen through Haynes #25 coated with Zr-Si.
2. Evaluation of the permeability of hydrogen through Haynes #25 coated with V.
3. Evaluation of hydrogen permeability through 304 stainless steel coated with V.
4. Evaluation of hydrogen permeability through tungsten.
5. Evaluation of hydrogen permeability through aged solaramic glass.
6. Re-evaluation of hydrogen permeability through aluminized and oxidized 304 stainless steel.

Figure 4 shows the permeability of hydrogen through Haynes #25 coated with vanadium and vanadium silicon coatings. Several other permeability measurements and samples are shown, such as the tungsten silicide coated Haynes #25 and the solaramic coated Haynes #25 to give a reference for comparison for the various samples.

The results of the experimentation with these materials indicate that the vanadium coated Haynes #25 and similar vanadium coated 304 stainless steel do not provide effective barriers to hydrogen. These results are shown in Figure 5. The V-Si coating on Haynes #25 had permeability slightly lower than previously tested siliconized Haynes #25, but did not exhibit the low permeability of the W-Si coating. Also, the V-Si coating upon re-cycling of the test specimen between 1200°F and 1600°F caused the coating to deteriorate and permeability resistance to decrease.

Testing of the Zr-Si coating applied to the Haynes #25 has been completed. These data along with the other silicide coatings are presented in Figure 6. The results of the test indicate that the Zr-Si coating froms a relatively good barrier to hydrogen permeation. X-ray and metallographic examinations have been completed on the silicide coatings. An interesting correlation exists between the melting point of the silicide coating and its effectiveness as a hydrogen barrier. The results of the testing have shown that as the melting point of the silicide increases, its permeability to hydrogen significantly decreases.

The Seiverts type hydrogen permeability test rig was modified to allow permeability measurements from metal tubes. With accurate calibrations of tube type samples,

PERMEABILITY OF HYDROGEN THROUGH HAYNES 25
COATED WITH VANADIUM AND VANADIUM-SILICON

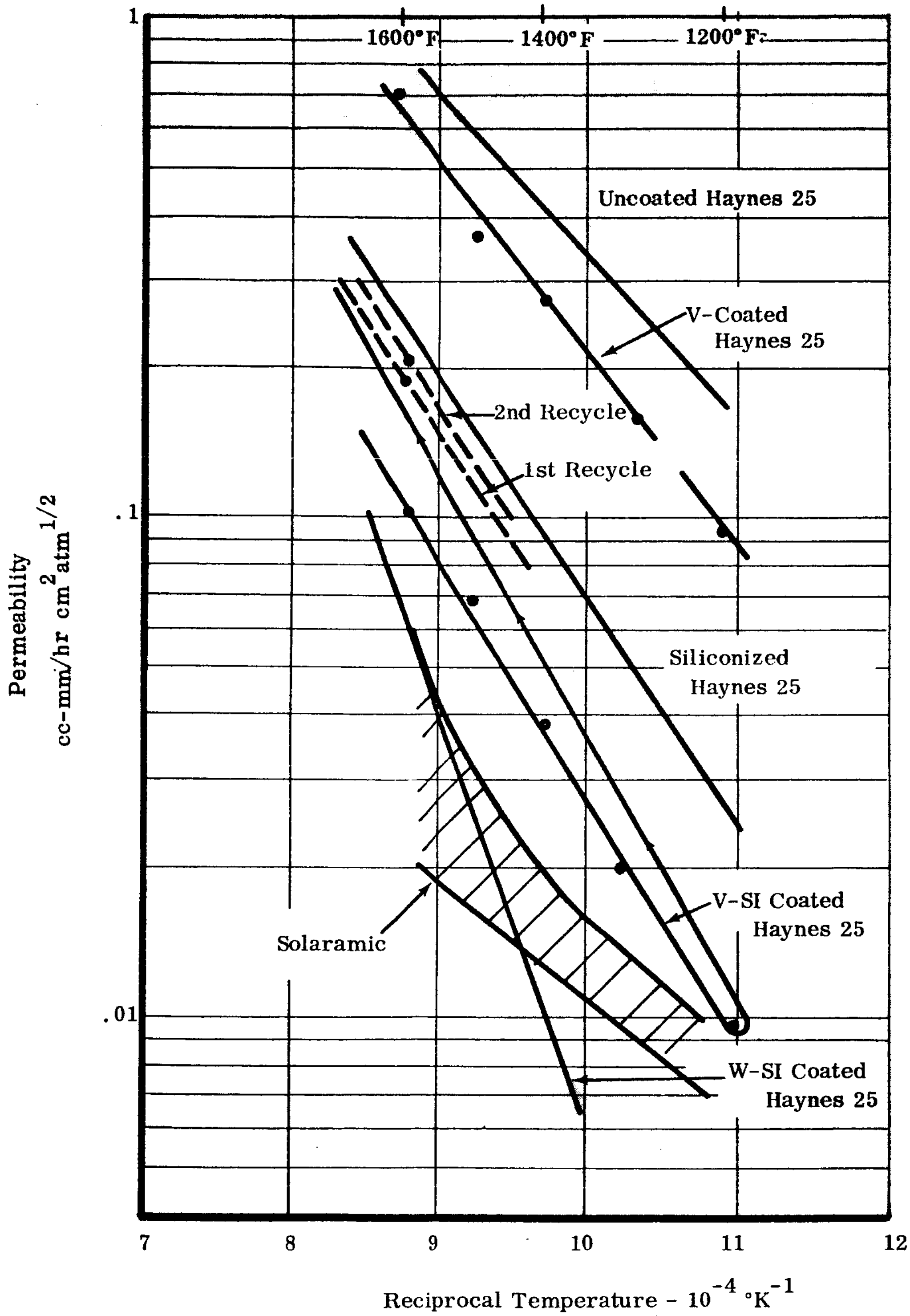


FIGURE 4

PERMEABILITY OF HYDROGEN THROUGH HAYNES 25 AND 304SS COATED WITH VANADIUM

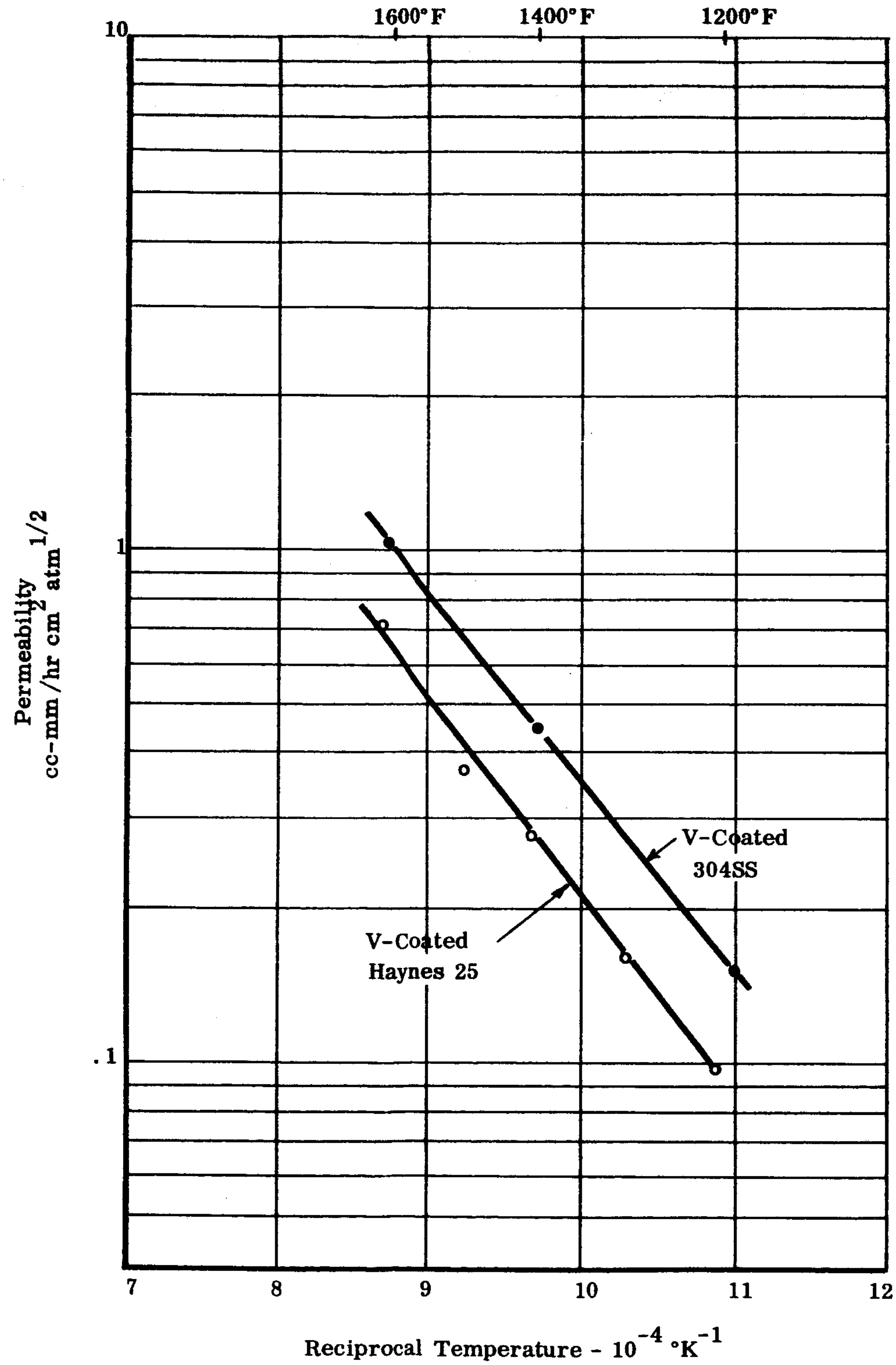


FIGURE 5

HYDROGEN PERMEABILITY OF VARIOUS METALS

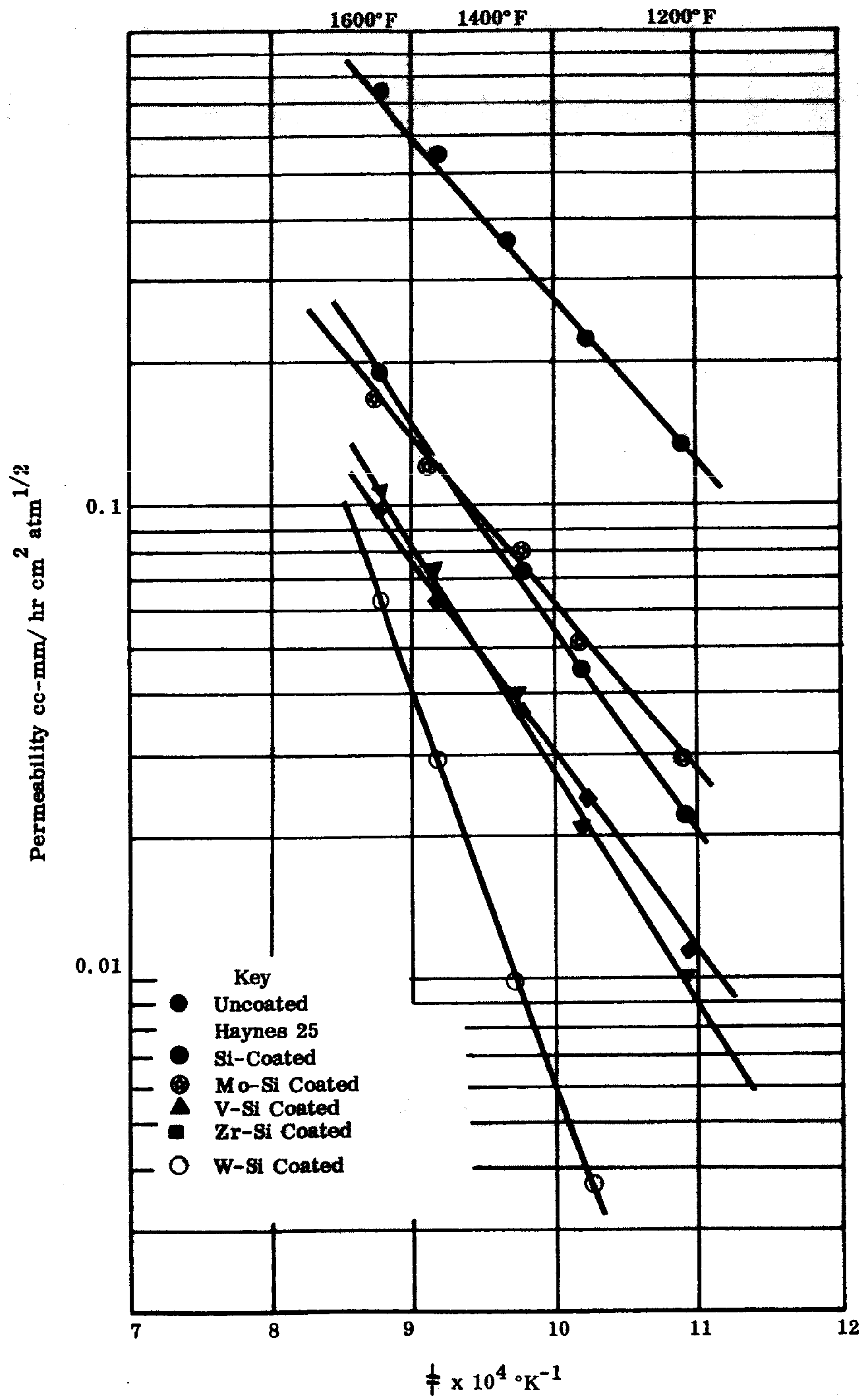


FIGURE 6

the use of the apparatus is extended to the refractory type materials. Tests of permeability of hydrogen through a tungsten sample were completed at elevated temperatures of 1300, 1400, 1500, and 1600°F. The data obtained from the tungsten coating show this to be the most effective barrier to hydrogen permeation yet investigated. The coating exhibits an order of magnitude better resistance to hydrogen permeation than solaramic or tungsten silicide coatings. Figure 7 illustrates the data obtained from the current series of tests.

Materials

The workhorse forced circulation mercury corrosion loop, as illustrated in Figure 8. was operated throughout the reporting period and tests conducted on the hydrogen swallowing capabilities of the Sunflower centrifugal pump and hydrogen removal tests were conducted using various removal techniques. After 3600 hours of operation, the workhorse loop testing program was terminated while revisions to the test loop were conducted. The following revisions were completed:

1. The centrifugal pump by-pass was revised prior to installation of a centrifugal separator and orifice flowmeter.

2. An iron Croloy 9M window was installed in the exit of the superheater.

3. A columbium section was installed as a hydrogen window in the condenser portion of the loop and additional hydrogen injection fittings were added immediately in front of the columbium window.

4. A tantalum corrosion product separator was installed at the superheater entrance.

During the period, evaluation of the hydrogen swallowing capabilities of the centrifugal pump was continued. Hydrogen was injected into the pump in various size bubbles from 0.2 cc to the volume of hydrogen that would cause loss of prime in increments of 0.2 cc. During the injection period, the speed of the pump was varied between 33,000 to 40,000 rpm in increments of 1,000 rpm, while the pump inlet pressure was maintained constant. The data illustrating the swallowing capabilities of the centrifugal pump, are shown in Table 1. In general, an optimum speed is indicated where the pump can pass the greatest hydrogen bubble. The data also suggest that increasing the inlet pressure of the pump significantly increases its ability to pass hydrogen bubbles. The optimum speed range of the pump usually varies between approximately 34,000 to 38,000 rpm. At inlet pressures above 11.5 psia, injection of hydrogen was not accompanied by a loss in prime of the pump with bubbles as large as 15 cc.

To complete the data on hydrogen swallowing capability of the centrifugal pump, future tests are to be conducted in which hydrogen is injected at a constant flow rate. In this series of tests, hydrogen will be injected by the apparatus depicted Figure 9. The procedure used will inject hydrogen at a specific flow rate while varying pump parameters such as inlet and outlet pressure and pump speed.

HYDROGEN PERMEABILITY OF TUNGSTEN

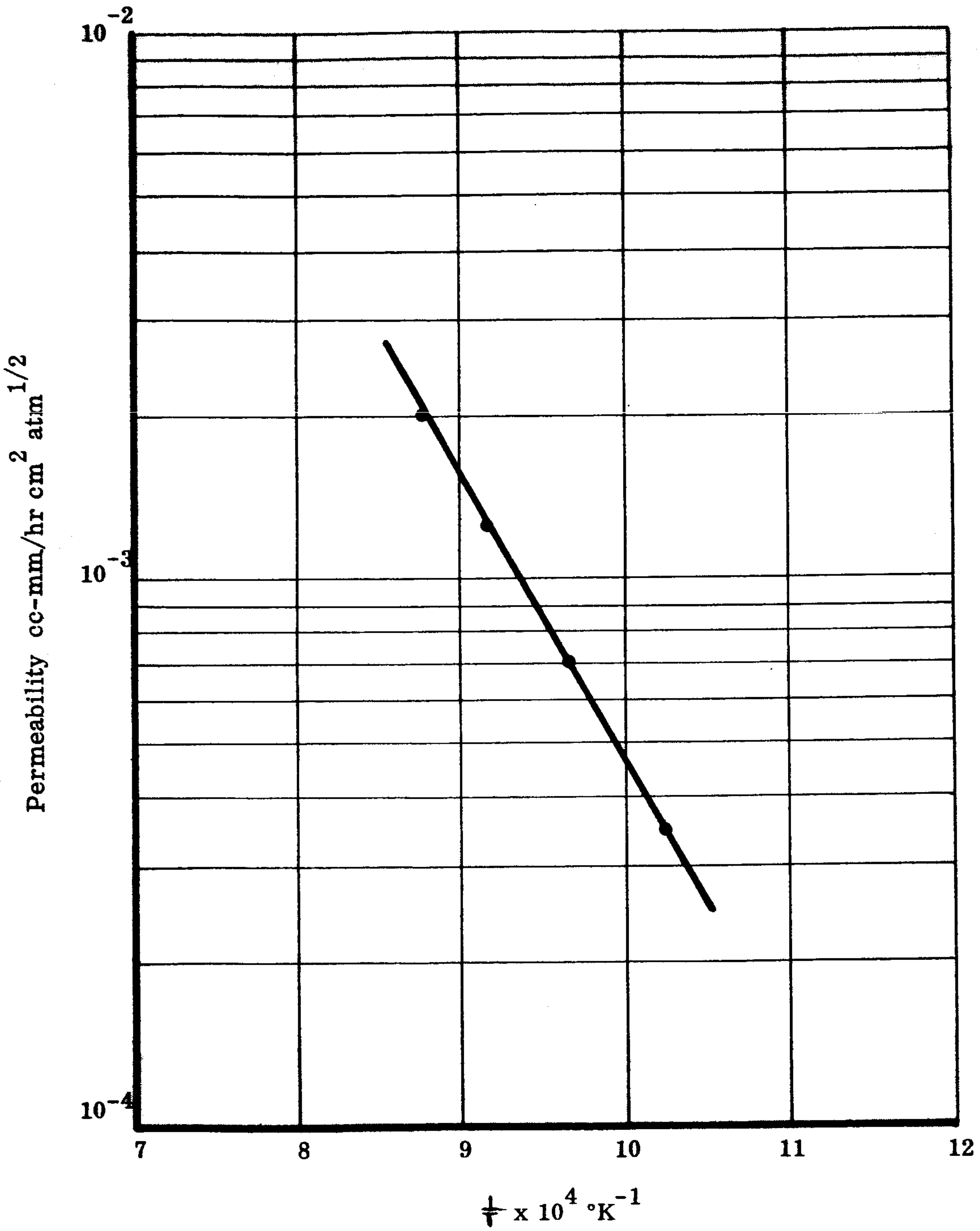


FIGURE 7

GEOMETRIC - WORKHORSE LOOP

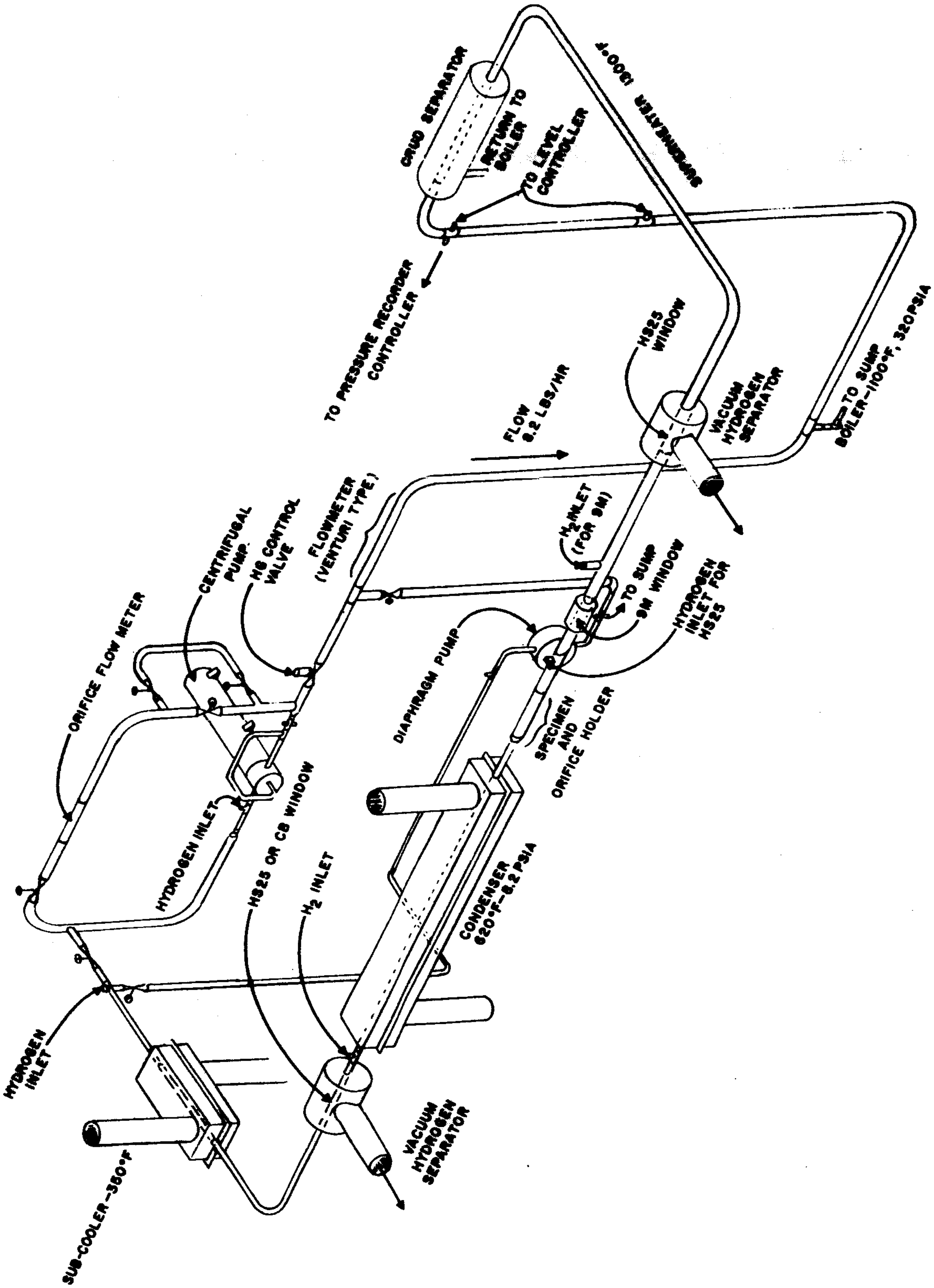
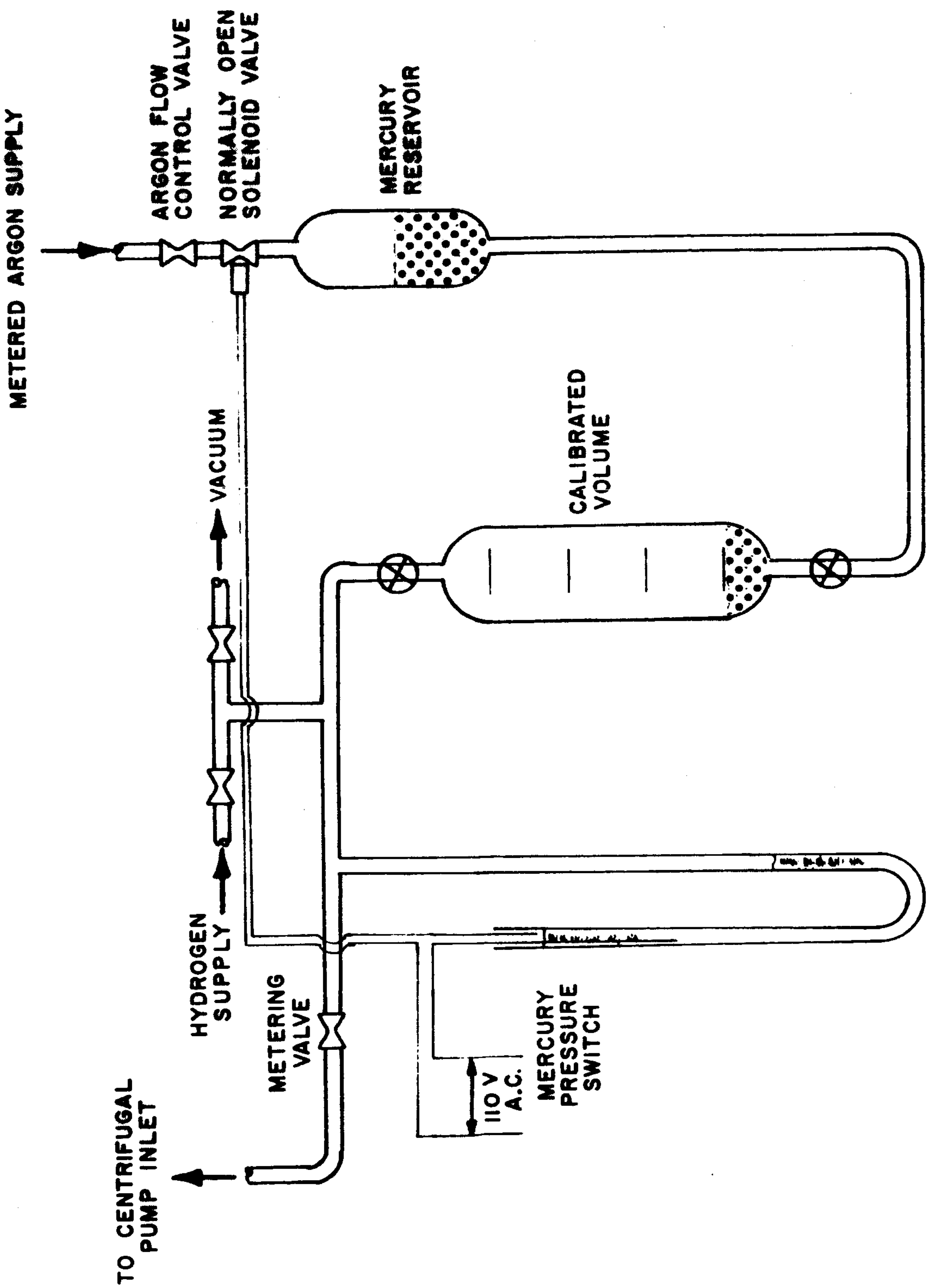


FIGURE 8

CENTRIFUGAL PUMP TESTING - SINGLE BUBBLE INJECTION

Pump Conditions		Optimum Conditions For Loss of Prime	
Inlet Pressure (psia)	Outlet Pressure (psia)	Pump Speed (rpm)	Bubble Size (cc)
5.5	200	37,500	0.9
	250	34,500	0.7
	300	34,000-36,000	$\geq$0.8 to 1.0
8.5	200	34,000-36,000	$\geq$1.8 to 2.4
	250	35,000-38,000	$\geq$2.0 to 3.0
	300	34,000-35,000	$\geq$2.4 to 2.6
11.5	200	Could not cause loss of prime even with bubble sizes up to 15 cc.	

TABLE 1



CONSTANT FLOW HYDROGEN INJECTION UNIT

FIGURE 9

Hydrogen removal tests from the workhorse loop were conducted and the data obtained are summarized in Table 2. Throughout these tests, several approaches, modifications, etc., have been tried in order to evaluate factors such as place and injection, window location, and temperature effects. In earlier tests, hydrogen was injected in the superheater section of the loop and removed to a sampling section comprised of the test loop rig material of Haynes #25. The results indicated that although hydrogen was injected in the superheater, it was trapping in the test loop and was not passing to the window section to allow proper evaluation. As a result, amounts of hydrogen removed from the system were small compared to the volume injected. Similar attempts were tried with movement of the hydrogen injection port to the condenser and subcooler portion of the loop. The results of these tests were quite similar to the other attempts and resulted in relatively minor amounts of hydrogen being removed from the system.

The latest revision to the loop included the use of a columbium window in the condenser section of the loop and a Croloy 9M window in the superheater of the loop. Hydrogen was injected into the loop immediately in front of the hydrogen window to preclude the hydrogen build-up in the system and transport difficulty which had been experienced previously. These tests showed an increase in the amount of hydrogen collected but improvement is still needed before application to the full scale system would be practical. The problem that has been encountered is the constant oxidation of the columbium window section, resulting in significant decreases in hydrogen permeability for the window section.

During preparation for the fourth test since the apparatus was modified, the leak rate of the system while connected to the columbium window increased. It was concluded that the Swagelok fittings used to secure the columbium tubing had developed a leak. Action is now in process to prevent this problem from influencing test results. Work will be continued to obtain more data on hydrogen removal techniques.

Additional work on the workhorse loop will be accomplished using active centrifugal separator techniques for removing hydrogen from the working fluid. The design of the centrifugal separator is basically a tangential entrance and axial outlet with a columbium window formed from 0.1875 in. O.D. columbium tubing. This apparatus is shown in Figure 10. The columbium tube is held within the stainless steel jacket by meands of Swagelock fittings. Basic operational principles involve imposing an artifical "g" field on the mercury such that the hydrogen gas can escape to form a cone section which will be surrounding the columbium inserted tube and will allow active removal of hydrogen to an evacuated system. The centrifugal separator will be placed in the workhorse loop in the discharge of the centrifugal pump outlet so that workable pressure drop is available without affecting the net positive section head of the inlet conditions of the centrifugal pump. During testing, hydrogen will be injected into the mercury at a constant rate. Details of the design of the separator include the following:

WORK-HORSE LOOP HYDROGEN INJECTION AND REMOVAL SUMMARY

Run No.	Injection Method	Injection Port Location	Collection Port Location	Collection Port Material	Temperature °F	Collecting System Check Time (Min.)	Collecting System Check Volume Collected (cc)	Collecting System Check Blank Rate (cc/hr.)	Injection Data Time (Min.)	Injection Data Injection Rate (cc/hr.)	Injection Data Volume Injected (cc)	Hydrogen Collection Time (Min.)	Hydrogen Collection Volume Collected (cc)	Hydrogen Collection Collection Rate (cc/hr.)	Hydrogen Collection Corrected Collection Rate (cc/hr.)
1	Constant Flow	Subcooler	Superheater	Haynes 25	1195	180	0.169	0.056	355	540	a	151	0.176	0.072	0.015
2	Constant Flow	Subcooler	Superheater	Haynes 25	1200	60	0.0615	0.0615	120	444	a	255	0.286	0.067	0.002
3	Constant Flow	Subcooler	Superheater	Haynes 25	1170	60	0.0505	0.0505	180	450	1350 (b)	300	27.4	5.48	5.43
4	Constant Volume	Superheater	Superheater	Haynes 25	1215	60	0.0696	0.0696	120	450	900	180	0.268	0.0953	0.026
5	Constant Volume	Superheater	Condenser	Haynes 25	560	157	0.0533	0.0205	50	13	11	1543	0.425	0.018	0
6	Constant Volume	Subcooler	Condenser	Haynes 25	650	77	0.0725	0.0565	150	9.5	24	2976	1.09	0.0218	0
7	Constant Volume	Subcooler	Condenser	Haynes 25	645	1152	0.137	0.007	180	32	96	2855	0.411	0.009	0.002
8	Constant Volume	Subcooler	Condenser	Columbium	595	72	0.0438	0.0365	310	10	51	360	0.189	0.0315	0.004
9	Constant Volume	Subcooler	Condenser	Columbium	600	6047	1.85	0.0183	160	9	24	420	0.274	0.0391	0.02
10	Constant Volume	Superheater	Condenser	Columbium	580	5880	1.19	0.0122	90	23	35	414	0.100	0.0145	0.002
11	Constant Volume	Condenser	Condenser	Columbium	550	20	0.032	0.096	60	100	100	25	0.13	0.31	0.28
			Superheater	Croloy 9M	1085	6	0.029	0.29				21	0.52	1.49	1.20
			Condenser	Columbium	550							38	0.61	0.96	0.93
			Superheater	Croloy 9M	1085	Blank Rates Same As Shown Above						9	0.21	1.40	1.10
12	Constant Volume	Condenser	Condenser	Columbium	675	35	0.025	0.042	115	100	125	30	0.026	0.052	0.010
			Superheater	Croloy 9M	1165	30	0.156	0.392				30	0.35	0.70	0.31
			Condenser	Columbium	675							40	0.25	0.33	0.29
			Superheater	Croloy 9M	1165	Blank Rates Same As Shown Above						63	1.1	1.05	0.65
13	Constant Volume	Condenser	Condenser	Columbium	675				40	100	67	40	0.111	0.17	0.13
			Superheater	Croloy 9M	1165							48	0.89	1.11	0.71
			Condenser	Columbium	675							66	0.30	0.73	0.69
			Superheater	Croloy 9M	1165							61	1.233	1.21	0.81
			Condenser	Columbium	675							22	0.14	0.38	0.34
			Superheater	Croloy 9M	1165							40	0.69	1.03	0.63

a. A negligible amount of hydrogen entered the loop.

b. Most of the hydrogen injected collected in the condenser-subcooler region and escaped when an attempt was made to bleed off mercury from the sub-cooler.

TABLE 2

WORKHORSE LOOP MERCURY - HYDROGEN CENTRIFUGAL SEPARATOR

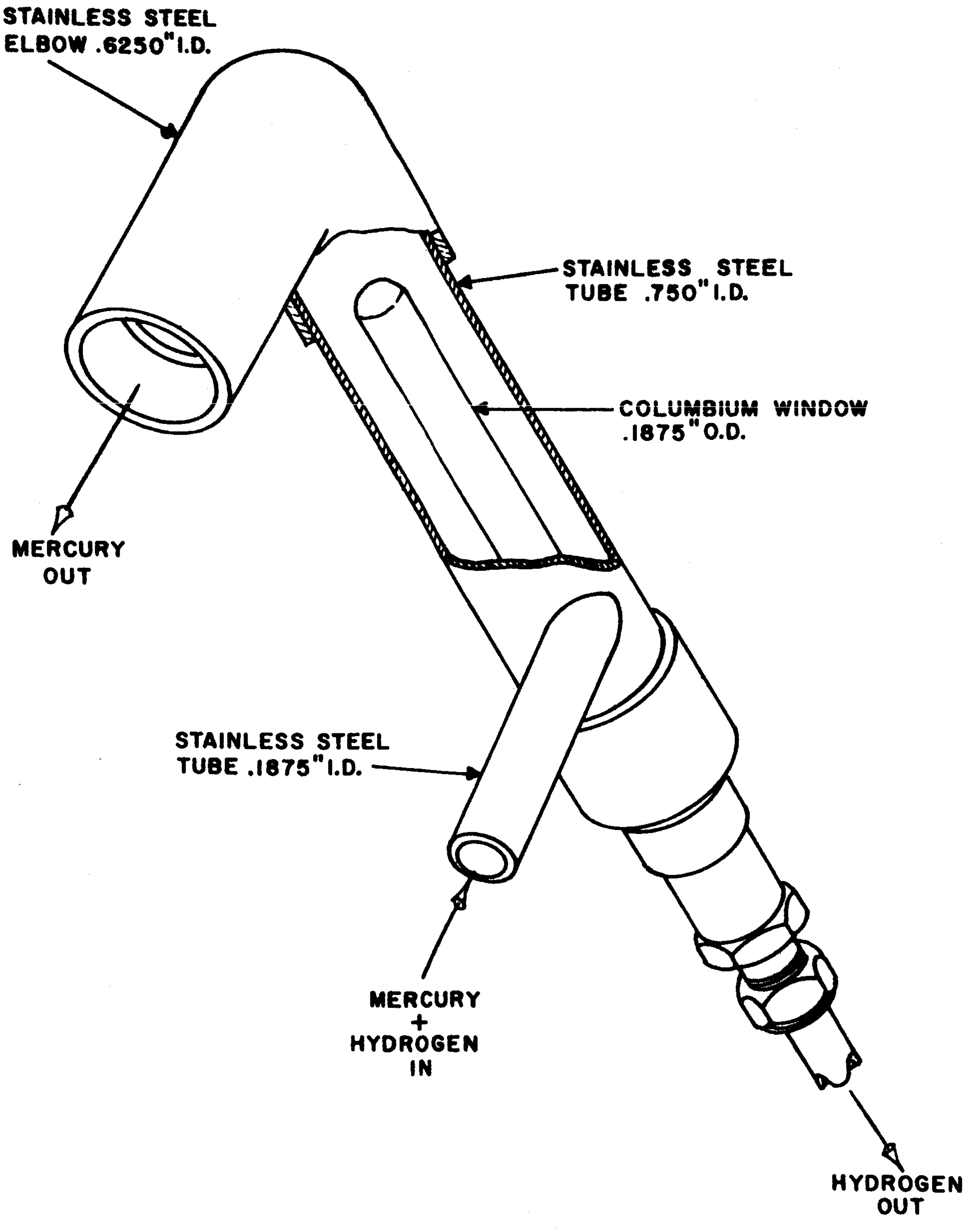


FIGURE 10

1. Flow rate: 34 lb/min
2. Inlet pressure: 350 psia
3. Inlet temperature: 400°F
4. Design to separate 0.2 lb per year of hydrogen

Operation of the four circulation mercury corrosion loops containing trapping provisions has progressed throughout the quarter. The test has operated successfully and has accumulated 2430 hrs. of operation. Several minor problems have been uncovered while performing active trapping in the corrosion loop. These have included the malfunction of the bellows of two Haynes #25 throttling valves and a malfunction of a diaphragm pump caused by improper operation of the ball check valves. These problems have been corrected and the loop has been operating satisfactorily.

Chemical and metallurgical analysis of previously tested capsules has continued.

IV. CURRENT PROBLEM AREAS

No technical problem areas currently exist on the program. All test phases of the program are progressing on schedule and should be completed within the program schedules.

V. PLANNED DIRECTION OF EFFORTS FOR THE NEXT QUARTER

Endurance testing of turboalternator CSU I-3A will be continued.

Operation of the workhorse loop will be continued and will be directed toward evaluating hydrogen swallowing capabilities of the centrifugal pump at constant hydrogen flow rate. In addition, continued evaluation of hydrogen removal techniques will be evaluated and completed. During the latter portion of the quarter, the current test program will be concluded and a tear-down and evaluation of the corrosion product separator and metallographic examinations of the loop will be initiated.

The force circulation corrosion loop testing will be continued toward an endurance objective of 5000 hr of operation.

Final printing of the Solar Collector and Condenser Subcooler Topical Reports will be completed and the reports distributed.

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